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Influence of Superposition and Splitting of Layers F_1 and F_2 over the Diurnal Variation of Ionosphere. *

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1. Introduction.

The author started observation of ionosphere at the Shanghai Science Institute in November, 1938 and has investigated $P'-f$ curve, which is also called $h-f$ curve with the echo height of ionosphere plotted for various frequencies, to observe critical frequencies or electron density and diurnal variation of apparent height of the layers.

The measuring apparatus used consists of a transmitter controled by hand to change its oscillation frequency and a receiver tuned to the transmitted frequency with a Braun tube oscillograph on which the height is read and recorded.

Transmitter : Input about 1 *kw.* Oscillator tube SN205C, Hartley self exciting circuit. 50 *cycle* a.c. for plate voltage.

Frequency Limits: 1.5 - - - 18 *MC*, with five interchangeable coils.

Pulse Generator : Neon discharge tube as a pulse source with a constant voltage applied. Pulse breadth 10^{-4}*sec*, 50*cycle/sec*. The phase of pulse is adjusted so as to coincide with the moment of maximum a. c. plate voltage.

Receiver : A superheterodyne set designed specially for ionosphere observation. Intermediate frequency 450*KC*. Band breadth 30*KC*.

Recorder : BT-140V oscillograph.

Observing with these apparatuses, the author was most impressed by the fact that in December and January or when the layer F_1 is not present in winter the critical frequency increases rapidly from sunrise and monotonously up to about 10 o'clock and decreases monotonously from 14—15 o'clock until about two hours after the sunset, while in seasons when the layer F_1 appears the electron density of F_2 that has steadily increased since before the sunrise, as soon as the layer F_1 appears as if splitting out of F_2 in its height, gets less in its increasing rate or sometimes a temporary concavity takes place on the curve. And in the evening when F_1 and F_2 are superposed the decreasing electron density increases temporarily to give the diurnal variation curve a convexity. This has been already described by Berkner as "bite-out effect" for the variation in the tropical regions. This phenomenon seems to take place earlier and earlier in the morning and later and later in the evening with the time of F_1's appearance in March, April and May.

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The writer believes that F_1 and F_2 are two different layers that change their relative height according to the sun's zenith distance and the layer F_1 is observed only when F_1 comes below F_2. When F_1 lies above F_2, F_1 can not be observed because the electron density of F_2 is greater than that of F_1 and every electromagnetic wave that gets through F_2 never fails to get through F_1. Followingly, what is usually called F_2 means a superposition of F_1 and F_2 observed together except when they are in an entirely separated state.

In our present paper, the above phenomenon is interpreted as a result of superposition and splitting of F_1 and F_2 caused by their change in relative height, a remark is made that the F_1's electron density curve of diurnal variation does not represent the maximum electron density except when F_1's N_{max} is entirely below F_2, and a difficulty shall be pointed out in calculating the true height of F_2 whose apparent one is severely influenced by the remarkable retardation of electromagnetic waves in F_1 when it is present.

2. Observed Facts.

As stated a little in the introduction, the daily variation curves of critical frequency and apparent layer height show almost every day a decrease in increasing rate or sometimes a concavity of F_2's critical frequency when F_1 and F_2 split vertically in the morning and a temporary increasing tendency of decreasing critical frequency when F_1 and F_2 come together in the evening. This fact may be mentioned distinctly on diurnal variation curves but not very distinctly on monthly average curves. Fig. 1 shows a

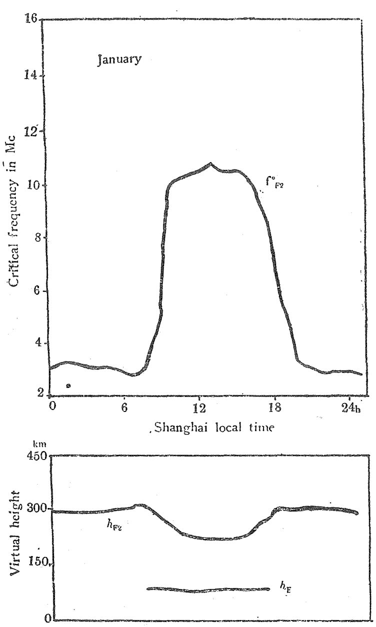

Fig. 1

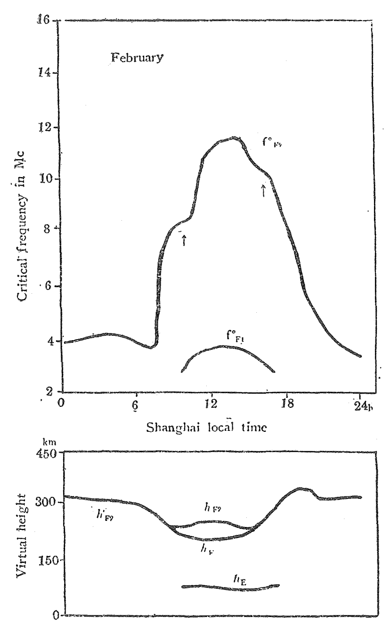

Fig. 2

typical diurnal variation in January. At this time of the year, F_1 does not appear at all. Before and after noon on the critical fequency curve, though not distinctly, some ups and downs seem to exist. The apparent height curve shows that F_2 comes lower at dawn, lowest at noon and gets higher again at night. In February, as shown in Fig. 2, F_1 appears very faintly just for some hours in the daytime. In this case, irregularities indicated with arrows in the figure appear on the F_2's critical frequency curve. The F_1's minimum apparent height varies just like F_2's h'_{min} in January and attains its minimum around noon. The height $h'(F_2)_{min}$ is not yet very different from $h'(F_1)_{min}$ and has its maximum around noon. In March as in Fig. 3 and later in April as in Fig. 4, F_1 grows more eminent, its presence longer, the ups and downs marked with arrows more eminent, the difference between $h'(F_2)_{min}$ and $h'(F_1)_{min}$ greater and F_2 very high.

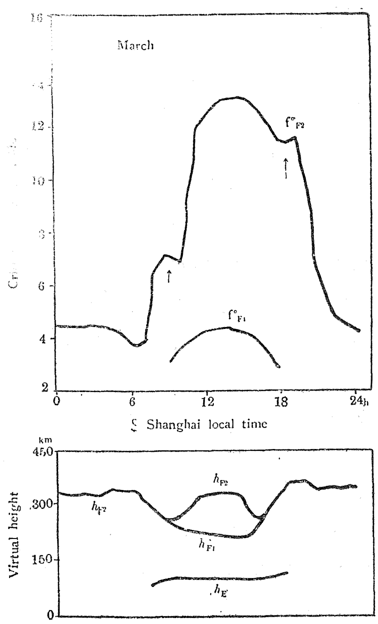

Fig. 3

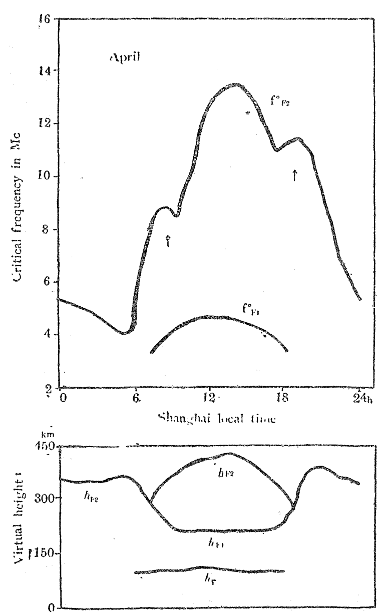

Fig. 4

The appearing and growing up of F_1 may be studied more closely with $P'-f$ curves. When the F_2's electron density is increasing rapidly at dawn, the curves have a simple form of F_2 only as shown in Fig. 5 (a). At the beginning of F_1's appearance, just appears a slight step as shown in Fig. 5 (b) which is apt to be missed in observation unless a lot of attention is paid. In the state of (c), it becomes rather distinct and F_1's ordinary and extraordinary waves in F_1 are separated and it grows up as shown in (d) and (e). In the state of (f) and (g), the level of maximum electron density of F_1 is supposed to have got through almost entirely below F_2 and the apparent height increases rapidly as the electromagnetic waves are separated into ordinary and extraordinary waves when they go through F_1. An observation with a gradually increasing frequency proves a

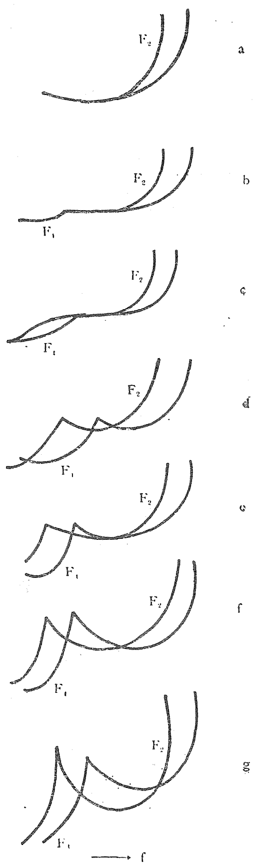

Fig. 5

gradual apparent height decrease at the transient height from F_1 and F_2. This is because of the group velocity retardation of electromagnetic waves through F_1 which gets less for shorter wave lengths. The F_2's apparent height attains its minimum at a certain point in the height-frequency curves or P'–f curves and for higher frequencies it increases again by penetrating through F_2. The critical frequency of F_2 is clearly recorded in case of Fig. 5 (e), (f) and (g), and, in such cases as (b) and (c), the frequency for the step point is usually recorded as critical frequency.

3. The Layer F_2.

Appleton observed the layer for the fist time by interference method and named it F as a single layer, which was later proved to consist apparently of two different layers namely F_1 and F_2 as shown in Fig. 5 when it was investigated by pulse method with varying frequencies.

F_1, as described above, is never observed for two or three months in winter in the regions of intermediate latitudes and in other terms of the year only in the daytime but never at night. In tropical regions it exists in the daytime all the year round but never at night. At higher latitudes its absence seems to be longer. Thus it seems not to appear unless the sun's zenith distance is smaller than a certain value. It is also supposed from the behaviour of P'–f curves and layer height diurnal variation curves that F_1 appears only in the daytime when the sun's zenith distance is less than a certain value and it gets into F_2 to disappear in winter and at night.

On the fundamental mechanism of F_1's appearance, there may be two possible points of view, namely, (a) A single layer formed by a single ionization agent is separated into two upper and lower layers only in the daytime, or, (b) F_1 and F_2 are entirely independent from each other originated from two different ionization agents absorbing different radiations from the sun. The none of them has been approved decisively yet, the latter seems more popular among the people concerned. The writer himself is also of the latter view point that these two layers are of different origins produced from two different ionization agents or one with two different energy levels by absorbing different radiations from the sun.

At high latitudes F_1 does not appear even in April, at intermediate latitudes not for one or two months in winter, while in tropical regions it does appear all the year round.

It appears only in the daytime and it seems to be high up and hidden in F_2 in the early morning and late in the evening. Thus the appearance of F_1 seems to be related to the sun's zenith distance χ and seems unlikely to appear when χ is over 55°.

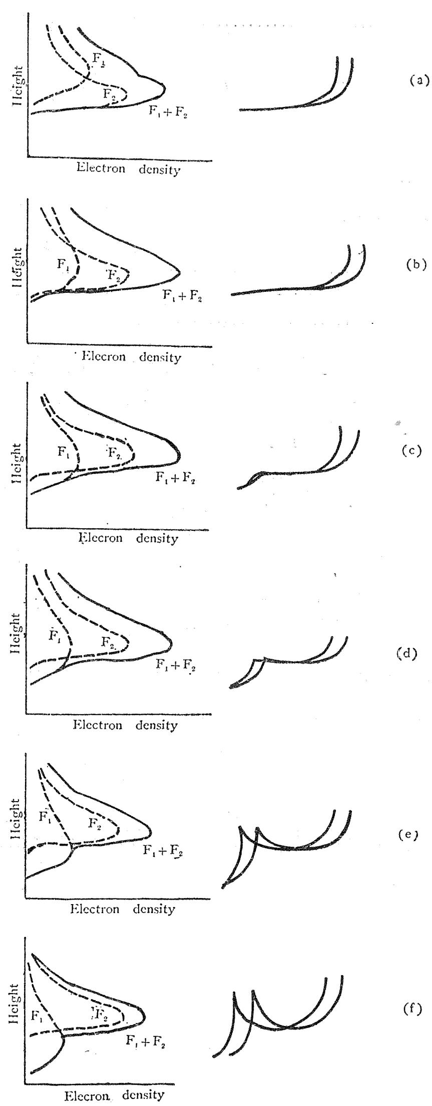

Fig. 6

As the electron density of F_2 is greater than that of F_1, F_1 will never be detected when they change their relative height with χ so that F_1 be above F_2 by our present means of observation with electromagnetic waves, because the waves that can pass through F_2 necessarily pass through F_1. P'–f curves in Fig. 5 also suggest a gradual descending of F_1 below F_2.

Thus, if we suppose the layers F_1 and F_2 are formed by two different kinds of solar radiations, it seems likely that we are not observing at least in the daytime a single layer but two layers F_1 and F_2 superposed to various degrees according to the variation of their relative height which is also probable to be affected to a good extent by their vertical electron density distribution. Judging from P'–f curves and apparent layer height, F_1 seems to change its height more remarkably after the sun's zenith distance.

Imaginary figures of an example of F_1 and F_2's superposition and corresponding P'–f curves are given in Fig. 6, in which are given various possible cases of superposition as well as F_1+F_2 observed usually as F_2. When the maximum of F_1 lies above the maximum of F_2 as shown in (a), they are observed as a single layer if the resultant electron density is given as the curve F_1+F_2. In case of (b), the electron density F_1+F_2 observed as F_2 takes the greatest value of N $(F_1)_{max}$+N$(F_2)_{max}$. With the successive coming down of the level of N $(F_1)_{max}$ or h $(F_1)_{max}$ below that of F_2 or h $(F_2)_{max}$ as shown in (c), (d), (e) and (f), N $(F_1+F_2)_{max}$ of superposed F_1+F_2 gets less and less. When the decreasing rate is greater than the increasing rate of N $(F_2)_{max}$ itself, a concavity appears on the diurnal variation curve and otherwise the increasing curve of diurnal variation becomes less steep.

4. Superposition of F_1 and F_2 in Chapman's Theory.

According to Chapman's theory,[1] the ionization is given by

$$I=\beta S_\infty A\rho_0 \ \exp\left\{-\frac{h}{\mathrm{H}}-\sec\chi A\rho_0\mathrm{H}\exp\left(-\frac{h}{\mathrm{H}}\right)\right\} \cdots\cdots (1)$$

where β=number of electrons produced by absorbing a unit energy of sun's radiation,

A=mass absorption coefficient.

$\mathrm{H}=kT/mg$=equivalent height of atmosphere.

The maximum electron production I_{max} and its height are given by

$$I_{max}=\frac{\beta S_\infty}{e\mathrm{H}}\cos\chi \cdots\cdots (2)$$

$$h_{max}=\mathrm{H}\log\ (\sec\chi A\rho_0\mathrm{H})=\mathrm{H}\log A\rho_0\mathrm{H}-\mathrm{H}\log\ \cos\chi \cdots\cdots (3)$$

By putting suffixes 1 and 2 for F_1 and F_2, respectively, we have for what is observed

$$I=I_1+I_2=\beta_1 S_{1\infty} A_1\rho_{10}\ \exp\left\{-\frac{h}{\mathrm{H}_1}-\sec\chi A_1\rho_{10}\mathrm{H}_1\exp\left(-\frac{h}{\mathrm{H}_1}\right)\right\}$$
$$+\beta_2 S_2 A_2\rho_{20}\exp\left\{-\frac{h}{\mathrm{H}_2}-\sec\chi A_2\rho_{20}\mathrm{H}_2\exp\left(-\frac{h}{\mathrm{H}_2}\right)\right\}$$

The relative height of F_1 and F_2 is

$$h_{2max}-h_{1max}=\mathrm{H}_2\log\ (\sec\chi A_2\rho_{20}\mathrm{H}_2)\ -\mathrm{H}_1\log\ (\sec\chi A_1\rho_{10}\mathrm{H}_1)$$
$$=\mathrm{H}_2\log A_2\rho_{20}\mathrm{H}_2-\mathrm{H}_1\log A_1\rho_{10}\mathrm{H}_1+(\mathrm{H}_1-\mathrm{H}_2)\ \log\cos\chi \cdots\cdots (4)$$

When the sun is at the zenith, $\chi=0$, $\cos\chi=1$ and F_2 is above F_1. Then gives

$$\mathrm{H}_2\log A_2\rho_{20}\mathrm{H}_2>\mathrm{H}_1\log A_1\rho_{10}\mathrm{H}_1 \cdots\cdots (5)$$

with

$$h_{2max}>h_{1max}.$$

As the sun's zenith distance gets greater, $h_{2max}-h_{1max}$ should get smaller. That is, h_{1max} varies with χ more rapidly than h_{2max}:

$$\frac{d\ (h_{2max}-h_{1max})}{d\chi}=\frac{\mathrm{H}_1-\mathrm{H}_2}{\cos\chi}\times(-\sin\chi)<0$$

or

$$\frac{d\ h_{2max}}{d\chi}<\frac{d\ h_{1max}}{d\chi}$$

Since $0°<\chi<90°$, both $\cos\chi$ and $\sin\chi>0$

$$\mathrm{H}_2-\mathrm{H}_1<0$$

or $$\mathrm{H}_2<\mathrm{H}_1 \cdots\cdots (6)$$

H=equivalent height $=kT/mg$.

$$\therefore\ \frac{T_2}{m_2}<\frac{T_1}{m_1}$$

In the daytime, if we sensibly assume $T_1\leqq T_2$, we have

$$m_2>m_1 \cdots\cdots (7)$$

From the conditions (6) and (7), a conclusion quite opposite to the general belief is obtained that the F_1's ionization agent consists of materials of smaller molecular weights than that of F_2. Therefore, the materials of F_1 may be found in higher air and its upward decreasing rate be less than that of F_2 That is, if F_2 is made form N_2 molecules, F_1 must be made from **0** atoms, after the result of the writer's former spectroscopical investigation on aurora.[2]

If the condions (5) and (6) are valid, it goes without saying that

$$\log A_2\rho_{20} > \log A_1\rho_{10} \quad \text{or} \quad A_2\rho_{20} > A_1\rho_{10} \quad \cdots\cdots(8)$$

that is, the product of absorption coefficient and ρ_0 of F_2 is greater than that of F_1.

The Chapman's formula of ion production may be also be written in the form

$$I = I_0 \exp\left\{1 - \frac{h-h_0}{\mathrm{H}} - \sec\chi \exp\left(-\frac{h-h_0}{\mathrm{H}}\right)\right\} = I_0 \exp\,(1 - z - \sec\chi e^{-z}) \cdots\cdots(9)$$

where,

$$I_0 = \frac{\beta S_\infty}{e\mathrm{H}},$$

$$h_0 = \mathrm{H}\log A\rho_0\mathrm{H},$$

$$z = \frac{h-h_0}{\mathrm{H}},$$

$h_0 = h_{max}$ with the sun's zenith distance $\chi = 0$.

When expressed as in (9), *I depends* solely upon z. Therefore, z means the distance from the standard heght h_0 measured in H as a unit. From $\mathrm{H}_1 > \mathrm{H}_2$, we may conclude that the real ion distribution of F_1 is more extensive than that of F_2 or F_1 is deeper than F_2. The condition (8) and $I_{2max} > I_{1max}$ do not seem to be contradictory because $I = \beta SA\rho$, and it is sensible to assume $A_2 > A_1$ taking into consideration the distribution of ionization agents and the fact that the changing rate of h_{1max} of F_1 with respect to χ is greater than that of h_{2max}.

Beside the above explanation after the Chapman's theory, the relative change of the heights of F_1 and F_2 with χ described in §3 may well be rationally understood after such a model that the F_1's ionization agent is made of lighter particles distributing more extensively and the penetration of radiation varies more greatly with the zenith distance χ because of its smaller absorption coefficient.

5. Interpretation of Ups and Downs of F_2's Diurnal Variation in the Morning and Afternoon.

As stated in §2, such ups and downs in diurnal electron density variation of F_2 that take place in the morning and afternoon as seen in Fig. 1, 2, 3 and 4 may interpreted as a result of variation of superposition degree caused by the relative height change of F_1

and F_2 discussed in §3 and §4. The electron density in both F_1 and F_2 increases steadily after the dawn of upper atmosphere with increasing solar altitude and radiation, and then the rate of this electron densty increasing is accelerated by F_1's relative coming down to F_2 from the state of (a) to (b) in Fig. 6, making their superposition closer. In the state of (b) of the closest superposition, what is practically observed is N $(F_2)_{max}+$ N $(F_1)_{max}$. With the sun rising still higher as the time elapses, the superposition gets less close and the increasing rate of the electron density is made smaller or, when the decrease in superposition degree proves more effective than the F_2's electron density increase, a temporary concavity appears on the diurnal variation curve. The up and down in the afternoon that suggest a superposition of F_1 and F_2 seem to be interpreted as an effect of changing superposititions degree caused by ascending F_2, just opposite to the phenomenon in the morning. In this case, changing in order of (f), (e), ……, (b), (a), the varying superposition of F_1 and F_2 gets closest at (b) and attains its highest electron density N $(F_2)_{max}+$N $(F_1)_{max}$. The Berkner's "bite-out effect" may also be interpreted as an influence of the above superposition as well as of F_2's expansion.

6. The Electron Density of F_1.

When only a step of height is found in an observation of ionosphere at the beginning of F_1's separation from F_2 as shown in Fig. 5 (b) and (c), the frequency corresponding to the cusp point on the curve is customarily recorded as the critical frequency. But, if we assume such a process of F_1's appearance as stated in §3 according to which the level of maximum electron density of F_1 is still hidden in F_2 at our present state the above mentioned critical frequency may never represent N $(F_1)_{max}$ but a value far below it. That is, it is only at and after the state (e) and (f) that f (F_{10}) may be regarded as an index of N $(F_1)_{max}$. Therefore the critical frequency curve of diurnal variation does not always represent the behavior of F_1's N $(F_1)_{max}$. Especially for 2 or 3 hours after the appearance in the morning and 2 or 3 hours before the extinction in the evening, it is considered to give values pretty lower than N $(F_1)_{max}$.

Therefore, it must be noticed here that the electron density calculated from critical frequency of F_1 with an assumption that N $(F_1)_{max}$ be proportional to f_c^{o2} (F_1) should give a value pretty smaller than the real one unlike the case of maximum electron density of a single layer.

7. The Influence of F_1 over the Apparent Height of F_2.

What we obtain in measuring the height of ionosphere is an apparent one but not the true one. The apparent height is meant by the time τ necessary for the electromagnetic waves to come down back again after refracted in the ionosphere, which gives the height when multiplied by c/2 where c means the light velocity. But the truth is that the waves propagate at their group velocity U and it takes them more time than they do at light velocity c. Therefore, the apparent height observed is always greater than the true height.

Now let us put h = apparent height, z = true height, z_0 = height of lower surface of ionosphere and μ = coefficient of refraction within the ionosphere, and, neglecting the influence of terrestial magnetism and mean collision frequency of electrons in comparison with the frequency of electromagnetic waves, we have $\mathrm{U}=c\mu$. For ordinary short wave, we may, with all the presence of terrestial magnetism, put $\mathrm{U}=c\mu$. Therefore,

$$h=\frac{1}{2}c\tau=c\int_0^z\frac{dz}{\mathrm{U}}=z_0+\int_{z_0}^z\frac{dz}{\mu} \qquad \cdots\cdots(10)$$

As μ is always smaller than 1 in the ionosphere,

$$h>z_0+(z-z_0) \qquad \therefore\ h>z$$

or the apparent height is always greater than the true one. For ordinary short waves,

$$\mu=\sqrt{1-\frac{e^2}{\pi m}\frac{\mathrm{N}}{f^2}} \qquad \cdots\cdots(11)$$

$$\therefore\ h-z_0=\int_{z_0}^z\frac{dz}{\sqrt{1-\frac{e^2}{\pi m}\frac{\mathrm{N}}{f^2}}} \qquad \cdots\cdots(12)$$

The electron density is a function of z and $\mu=0$ at the heighest point or the point of reflection of the electromagnetic waves. Thus

$$\mathrm{N}_0=\frac{\pi m}{e^2}f^2$$

and

$$h-z_0=\int_0^{\mathrm{N}_0}\frac{d\mathrm{N}}{\sqrt{1-\frac{\mathrm{N}}{\mathrm{N}_0}}}\frac{1}{\frac{d\mathrm{N}}{dz}} \qquad \cdots\cdots(13)$$

In the equation (13), h is observed as a function of f and, therefore, it is a function of N_0. The integral equation (13) can be solved when h and $d\mathrm{N}/dz$ are continuous, giving

$$\frac{1}{\frac{d\mathrm{N}}{dz}}=\frac{1}{\pi}\frac{d}{d\mathrm{N}}\int_0^{\mathrm{N}}\frac{h-z_0}{\sqrt{\mathrm{N}-\mathrm{N}_0}}\frac{1}{\sqrt{\mathrm{N}_0}}d\mathrm{N}_0$$

By carrying out the integration,

$$z=\frac{1}{\pi}\int_0^{\mathrm{N}}\frac{h-z_0}{\sqrt{\mathrm{N}-\mathrm{N}_0}}\frac{1}{\sqrt{\mathrm{N}_0}}d\mathrm{N}_0 \qquad \cdots\cdots(14)$$

$$z=\frac{2}{\pi}\int_0^{f_1}\frac{h-z_0}{\sqrt{f_1^2-f^2}}df \qquad \cdots\cdots(15)$$

where $h(f)-z_0$ may be known by observation and the equation (15) enables us to calculate the true height of reflection and the retardation of electromagnetic waves in the ionosphere from the $P'-f$ curve when the layer is a single one.

But, when we apply the above result to F_2 at the presence of F_1, some errors accompany the result from the neglection of conditions charged upon (13) that both h and $d\mathrm{N}/dz$ be continuous. Further in such cases as shown in Fig. 6 (e) and (f) where the maximum region of F_1 is found entirely below F_2, z_0 for F_2 cannot be uniquely determined as h and dN/dz are not continuous and the electron density of F_1 above the height of N $(F_1)_{max}$ as well as the retardation of the waves they suffer as they pass through from F_1 to F_2 are unknown. Therefore, it seems rather difficult to obtain the true height of F_2 or the retardation of the waves. In fact, the F_2 gets very higher when F_1 appears. The sensible conclusion is that the layer height be lower at noon as the solar zenith distance is smaller and its radiation comes through deeper into the atmosphere. It is really as sensible as described above in winter when F_1 does not appear, while in other seasons when F_1 does appear the layer is, on the contrary, higher at noon. It is true that the expansion of F_2 may be considered as a factor but we should pay attention to the fact that the group velocity retardation of waves passing through F_1 is remarkable and consequently F_2 appears as if it were higher.

The foumula (15) may be properly adopted for a single layer and it is desirable to obtain a method to calculate theoretically the true height applicable to cases of such complex layers as F_2.

8. Conclusion.

From the point of view that F_1 and F_2 are of entirely different origins, the author interpreted the appearance of F_1 by the ionization of two different agents absorbing different radiations from the sun, and, he thinks, F_1 and F_2 with their relative height changing with the solar zenith distance χ are superposed on each other and F_1 is observed only when it is below F_2. Then it follows that what is called F_2 as a single layer is, to some extent, a superposition of F_1 and F_2 and their degree of superposition varies with the solar zenith distance.

Investigating the relative height variation after the model of Chapman, it results that $m_2 > m_1$ or the molecular weight of particles which make F_2 is greater than that of those which make F_1, which is just opposite to what has been generally believed, and that $A_2 \rho_{20} > A_1 \rho_{10}$ for the absorption coefficients.

The remarkable ups and downs in the morning and afternoon on the electron density diurnal variation curves of F_2 also seem to be interpreted as a phenomenon caused by the superposition and splitting of F_1 and F_2. It was also noticed that what is recorded as the critical frequency in the observation of F_1 does not always represent its maximum electron density and the apparent height of F_2 is observed as if it were higher than it really is when F_1 is present as the electromagnetic waves suffer a remarkable retardation as they pass through F_1. It was also pointed out that the calculation of true layer height is applicable to a single layer but it is difficult to apply it to such complex layers as F_2 is when F_1 is present.

The author herewith expresses his hearty thanks to the Soul of late Professor Shinzo Shinjo who suggested him studies in the field of ionosphere.

1. Chapman : Proc. Roy Soc. A 43. 483 (1931)

2. K. Senda ; Journ. Shanghai Science Institute. I, 1. 163 (1938)